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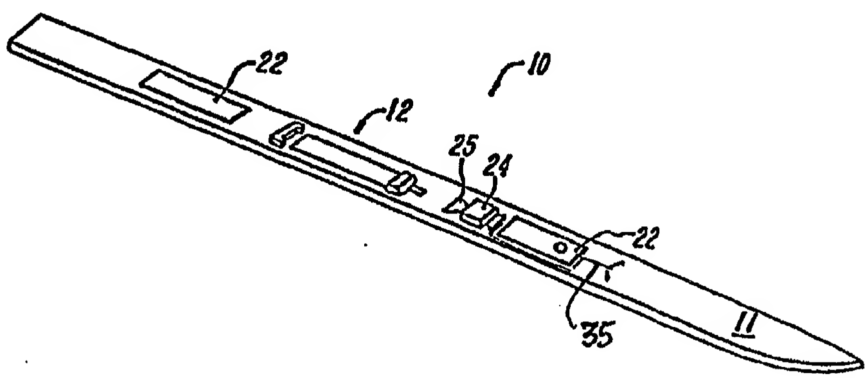

(57) Abstract

A sports implement, such as a ski includes a strain transducer material, such as layer containing a piezoceramic, mechanically coupled over a region of its body, and a circuit attached to or switched across the material to couple strain energy out of the implement and enhance its performance. For a ski, one effective circuit is a low Q resonant inductive shunt tuned to a performance band of the ski which enhances dissipation of energy in a neighborhood of a structural mode of the ski. The mode may be selected based on detected or anticipated ski operating conditions, while the neighborhood may be defined to include variations in the frequency of a first or higher free structural resonance which arise from production variations or size variations of the ski or its components. The neighborhood may also be selected to cover the range of frquencies that mode takes when driven by actual disturbances in use, such as the vibrations excited when skiing at a particular range of speeds, or with a particular set of snow conditions, or a combination of conditions of temperature, speed, snow and terrain.

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ADAPTIVE SPORTS IMPLEMENT WITH SELECTABLE OR TUNED DAMPING

Background of the Invention

The present invention relates to sports equipment, and more particularly to damping, controlling vibrations and affecting stiffness of sports equipment, such as a racquet, ski, or the like. In general, a great many sports employ implements which are subject to either isolated extremely strong impacts, or to large but dynamically varying forces exerted over longer intervals of time or over a large portion of their body. Thus, for example, implements such as baseball bats, playing racquets, sticks and mallets are each subject very high intensity impact applied to a fixed or variable point of their playing surface and propagating along an elongated handle that is held by the player. With such implements, the speed, performance or handling of the striking implement itself may be affected by the impact, and the resultant vibration may strongly jar the person holding it. Other sporting equipment, such as sleds, bicycles or skis, may be subjected to extreme impact as well as to diffuse stresses applied over a protracted area and a continuous period of time, and may evolve complex mechanical responses thereto. These responses may excite vibrations or may alter the shape of runners, frame, or chassis structures, or other air- or ground-contacting surfaces. In this case, the vibrations or deformations have a direct impact both on the degree of control which the athlete, such as a skier, may exert over his path of movement, and on the net speed or efficiency of motion achievable therewith.

Taking by way of example the instance of downhill or slalom skis, basic mechanical considerations have long dictated that this equipment be formed of flexible yet highly stiff material having a slight curvature in the longitudinal and preferably also in the traverse directions. Such long, stiff plate-like members are inherently subject to a high degree of ringing and structural vibration, whether they be constructed of metal, wood, fibers, epoxy or some composite or combination thereof. In general, the location of the skier's weight centrally over the middle of the ski provides a generally fixed region of contact with the ground so that very slight changes in the skier's posture and weight-bearing attitude are effective to bring the various edges and running surfaces of the ski into optimal skiing positions with respect to the underlying terrain. This allows control of steering and travel speed, provided that the underlying snow or ice has sufficient amount of yield and the travel velocity remains sufficiently low. However, the extent of flutter and vibration arising at higher speeds and on irregular, bumpy, icy surfaces can seriously degrade performance. In particular, mechanical vibration leads to an increase in the apparent frictional forces or net drag exerted against the ski by the

underlying surface, or may lead to a loss of control when blade-like edges are displaced so much that they fail to contact the ground. This problem particularly arises with modern skis, and analogous problems arise with golf clubs, tennis racquets and the like made with metals and synthetic materials that may exhibit much higher stiffness and elasticity than wood.

One practical approach for controlling vibration from arising has been to incorporate in a sports article such as a ski, an inelastic material which adds damping to the overall structure. Because of the trade-offs in weight, strength, stiffness and flexibility that are inherent in the approach of adding inelastic elements onto a ski, it is highly desirable to develop other, and improved, methods and structures for vibration control. Applicants have previously described in U.S. Patent 5,687,462 a modular and robust construction for a strain transducer unit which can not only change its own shape, but which couples strain across a substantial surface region. Applicants have furthermore described, in U.S. Patent Application 08/536,067 and corresponding International Application PCT/US96/15557 a construction wherein such strain transducer units are coupled in defined regions of a sports implement together with an active or passive circuit to damp, shift or otherwise control behavior of the implement under conditions of dynamic stimulation.

As described in that international application a sports damper is achieved wherein all or a portion of the body of a piece of sporting equipment has mounted thereto an electroactive assembly such as a piezoelectric sheet, which couples strain across a region of the body of the sporting implement and alters the damping or stiffness of the body. A circuit across the assembly adds or dissipates energy, effectively damping vibration as it arises, or altering the stiffness, thus changing the dynamic response of the equipment. The sporting implement is characterized as having a body with a root and one or more principal structural modes each of which has one or more nodes and regions of strain. The electroactive assembly is generally positioned near the root, to enhance or maximize its mechanical actuation efficiency. The assembly may be operated as a passive component, converting strain energy to electrical energy and shunting the electrical energy, thus dissipating energy in the body of the sports implement. Alternatively it may be an active embodiment, in which the circuit operates with a separate power source such as a replaceable battery. In this case, the battery is connected to a driver to selectively vary the mechanics of the assembly. For example, a sensing member in proximity to the piezoelectric sheet material may respond to dynamic conditions of strain occurring in the sports implement and provide output signals which are amplified by the power source for actuation of the piezo sheet. A controller may

include logic or circuitry to apply two or more different control rules for actuation of the sheet in response to the sensed signals, effecting different actuations of the piezo sheet.

In one described construction of such a damper in a ski, a single modular electroactive assembly is surface bonded to or embedded within the body of the ski at a position a short distance ahead of the effective root location, i.e., ahead of the boot mounting. In a passive construction, the charge across the piezo elements in the assembly is shunted to dissipate the energy of strain coupled into the assembly, while in an active embodiment, a longitudinally-displaced but effectively collocated sensor detects strain in the ski, and creates an output signal which is used as input or control signal for a driver which actuates the piezo sheet. A single 9-volt battery powers an amplifier for the output signal, and this arrangement applies sufficient power for up to a day or more to operate the electroactive assembly as an active damping or stiffening control mechanism, shifting or dampening resonances of the ski and enhancing the degree of ground contact and the magnitude of attainable speeds. The foregoing technique is of general applicability; in other sports implements the piezoelectric element may attach to the handle or head of a racquet or striking implement to enhance handling characteristics, feel and performance.

As described in the aforesaid international patent application, by using a passive resistive shunt control technique, the strain transducers are only able to effect a small level of damping, but this is applied over a broad frequency band. Thus, they are configured to continuously dissipate or redirect energy to prevent the build-up of vibrations. To do this the strain elements are preferably mounted in locations where they can capture strain energy from several excited modes. Further details of that construction are given in the aforesaid U.S. patent and the International patent application, which are hereby incorporated by reference.

However, in practice, an implement such as a ski is subject to very large disturbances at various frequencies depending upon the user and the environment. Thus, the shear-mounted strain element might not be able to affect the vibration levels occurring under some conditions, while in others practical experience and close observation may reveal particular states that could be advantageously controlled by coupled strain elements.

It is therefore desirable to increase the effectiveness of a strain element damper in a sports implement such as a ski.

It is also desirable to provide a dynamic strain element controller that is effective in the face of variations in the dynamics of the implement.

It is also desirable to provide a dynamic strain element controller that is effective in the face of variations occurring in electrical components used in the construction of the controller.

It is also desirable in particular to provide a strain element coupled to a ski and having an electrical control circuit tuned to a narrow ski frequency response band, wherein the response band encompasses a range of frequencies which may vary, due for example to velocity, terrain or device size and fabrication tolerances.

It is also desirable to provide a dynamic strain element controller that changes its control parameters to meet conditions of use.

It is also desirable in particular to provide a strain element coupled to a ski and having an electrical control circuit which responds to selection commands entered or transmitted by a user.

It is also desirable to provide a controller which enhances the levels of damping at one or more specific narrow frequency bands.

Summary of the Invention

This is achieved in accordance with one aspect of the present invention by providing a sports implement with a strain transducer mechanically shear-coupled to the implement and electrically coupled in a band-optimized shunt or driver circuit. In an illustrative embodiment, the implement is a ski and the ski has a strain assembly including one or more piezoelectric plates which are strain-coupled to the body of the ski, and which are electrically shunted by an R-L circuit. The resistor and inductor components together with the capacitance of the plates form a tuned circuit, of which the component values are selected such that the circuit preferentially shunts the electrical charge in the strain element over a frequency band surrounding a nominal target mode of the ski, to damp motion of the ski. Band width is chosen based on an expected range of ski modal frequency values to include variations due to manufacturing and ski component variations, or to cover the range of frequencies at which a given mode(s) may be forced as driving conditions vary. Preferably the band is broad enough to include both sources of variation, but excludes a range of frequencies characteristic of a distinct mode. In one embodiment, an inductive shunt circuit tuned to 80-120 Hz reduces vibration of the third structural mode of a ski by over fifty percent to enhance high-speed or frequent-impact skiing, but has lesser, or relatively little effect on the lower frequency first mode, at 10-15 Hz, which is not appreciably excited under these skiing conditions.

In accordance with another aspect of the invention, the strain transducer is provided with a selector configured to switch between several circuits which act to shunt and dissipate energy from the strain transducer, or otherwise control strain with different

responses or with different spectral characteristics. In an illustrative embodiment, the ski has a strain assembly including one or more piezoelectric plates which are mounted to the body of the ski, and which are electrically switched to be shunted by one of a set of shunt loops each having different tuning and/or power dissipation characteristics. The shunt circuits may include an R-L circuit, a resistor, or several R-L or resistor shunt circuits, each circuit being effective to dissipate charge arising in the piezo plates. The resistor, or the resistor and inductor components of at least one shunt circuit together with the capacitance of the plates preferably forms a tuned shunt circuit, of which the component values are selected such that the circuit preferentially shunts the electrical charge in the strain element over a frequency band in a neighborhood surrounding one or more nominal target modes of the ski, so as to more effectively damp specific vibrations or motion of the ski. In the case of a narrow band R-L shunt, the band width may be chosen based on an expected range of ski modal frequency values, to include variations due to manufacturing and ski component variations, or to otherwise include a range of frequencies as described further below. When a narrow band resonant shunt is provided, preferably its band is broad enough to include variations arising from components of the ski construction and from its environment or use, but it is tuned so it either has insubstantial damping effect at frequencies distinct from the targeted mode, or operates with different efficiency away from that mode. One or more of the circuits placed across the ski may include a storage circuit, which holds and returns electrical energy caused by strain in the plates, or a drive circuit, which provides additional charge to actively drive the plates.

In general, the selector includes a switching element on the ski which is actuated by the user to place one or another of the shunt circuits across the piezo sheet, and to thus alter the dynamic response of the ski in accordance with the predetermined characteristics of the selected shunt, to suit ski conditions. Preferably, the switch is actuated by a separate user selection controller, such as a wireless transmitter carried by the user to actuate the switching element. In one embodiment, the transmitter is an RF transmitter contained in a small unit worn or carried by the user, for example worn on a wrist or arm band, or attached to a belt, a glove or a ski pole. A receiving circuit located at the switch on the ski receives and demodulates the transmission emitted by the control unit to produce, in various embodiments, either a toggle signal or one of several code signals indicative of a desired switch state, and applies this signal to a switch circuit element to switch in the shunt circuit corresponding to the selected state.

In a preferred embodiment, two shunt circuits are provided and their power dissipation characteristics are tailored to provide effective damping at two distinct ski performance levels. The first shunt may be a resistor which dissipates power fairly

uniformly over the output spectrum of the piezo sheet, while the second shunt may be a tuned R-L shunt which preferentially enhances voltage at one or more vibrational modes or modal frequency bands of the ski and dissipates the enhanced voltage. The resistive shunt may be a shunt as described, for example, in the aforesaid U.S. patent, while the inductive shunt may be an R-L shunt tuned as described further below. At least one shunt preferentially damps a higher vibrational mode or modes of the ski. The user-held transmitter may include indicator lights to show the selected damping control state, and or may further include a receiver that receives confirmation signals indicative of the state of operation of the switch unit. In various implementations, the switch element may operate with a latch, or may be implemented with one or more solid state switching circuit elements. Power to operate the latch or semiconductor switch may be provided, for example, from a battery, or from a capacitor storage device which is charged directly by the output of a piezo element. The invention also contemplates remote control using other forms of transmission, such as ultrasonic or infrared transmission, and corresponding reception units, for coupling the remote controller to the switching circuit.

Brief Description of the Drawings

These and other features of the invention will be understood from the description contained herein taken together with the illustrative drawings, wherein

FIGURE 1 shows a ski in accordance with the present invention;

FIGURE 1A and 1B show details of a passive damper embodiment of the ski of FIGURE 1;

FIGURE 2 illustrates representative mode excitations in a ski under two different conditions of use;

FIGURE 3 illustrates representative damping of a mode with a highly tuned piezo shunt circuit;

FIGURE 3A is a comparative graph contrasting the damper of FIGURE 3 with the damper achieved by a band-tuned shunt of the present invention;

FIGURE 4 illustrates a remotely-switched multiple-damping embodiment of the invention; and

FIGURES 5A and 5B illustrate golf club and tennis racquet embodiments of the invention.

Detailed Description

FIGURE 1 shows by way of example as an illustrative sports implement, a ski 10 embodying the present invention. Ski 10 has a generally elongated body 11, and mounting portion 12 centrally located along its length, which, for example, in a downhill ski includes one or more ski-boot support plates affixed to its surface, as well as a sheet of visco-elastic damping material, and heel and/or toe safety release mechanisms (not shown) fastened to the ski behind and ahead of the boot mounting plates, respectively. These latter elements are all conventional, and are not illustrated. It will be appreciated, however, that these features define a plate-mechanical system wherein the weight of a skier is centrally clamped on the ski, and makes this central portion a fixed point (inertially, and sometimes to ground) of the structure, so that the mounting region generally is, mechanically speaking, a root of a plate which extends outwardly therefrom along an axis in both directions. As further illustrated in FIGURE 1, ski 10 of the present invention has an electroactive assembly 22 including a piezoelectric actuation sheet integrated with the ski or affixed thereto, and a controller 24 in electrical communication with the electroactive sheet element. In some embodiments, a sensing sheet element 25 is provided in communication with the controller 24.

As more fully described in the aforesaid international patent application, the electroactive assembly and its piezoelectric sheet element are strain-coupled either within or to the surface of the ski, becoming an integral part of and providing stiffness to the ski body, and responding to strain therein by changing its electrical charge state. A circuit is attached to the strain element so as to apply or to dissipate electrical charge, thus changing the strain energy to control vibrational modes of the ski and its response. The electroactive sheet elements 22 are preferably formed of piezoceramic material, which has a relatively high stiffness and high strain actuation efficiency. The exact location and positioning as well as the dimensioning and selection of suitable material is a matter of some technical importance both for a ski and for any other sports implement, as will be understood from the discussion in the aforesaid international patent application, and reference is made thereto for specific factors to consider in implementing this construction.

In general, the piezo actuation sheet assembly may be substantially similar to the QUICKPACK actuators, a commercial product packaged electroactive assembly sold by ACX, Inc. of Cambridge, Massachusetts. Reference is made to U.S. Patent 5,687,462 for further description of the properties and methods of robust fabrication of such thin stiff cards with sheet members in which substantially the entire area is occupied by one or more piezoceramic sheets encapsulated in a manner to provide a tough supporting structure for the delicate piezo member, yet to allow its in-plane energy to be efficiently coupled across one or both of its major faces. Accordingly, it will be understood in the discussion below that the electroactive sheet elements described herein are preferably substantially similar or identical to those described in the aforesaid patent application, or are elements which are embedded in, or supported by sheet material as described therein such that their coupling to the skis provides a non-lossy and highly effective transfer of strain energy therebetween across a broad area piezo actuator surface. However, in accordance with one aspect of the present invention, a band-tuned shunt is provided across the sheet to provide a robust and effective damping of a targeted vibration.

As further shown in FIGURE 1, in a preferred embodiment the control unit 24 is operated with a switching function, and an antenna 35 connects to the power control unit 24 to pick up control signals from a control transmitter 35' which is shown as a small unit carried by the user. Control transmitter 35' may for example be implemented in a wristwatch-like transmitter unit or may be embodied in an arm band unit or a clip-on unit which attaches to a ski pole or otherwise mounts conveniently on or accessible to the skier.

In accordance with a principal aspect of the present invention, the control unit 24 preferably responds to the signal sent by the transmitter 35' and received via antenna 35 or other receiving unit, to selectively switch in one of several distinct circuits across the piezo plates 22. These may include simple resistive shunts, band-optimized shunts, and various filtered shunt combinations, of which several representative examples are shown in FIGURES 1A and 1B and a preferred performance shunt is discussed in detail below. The controller may also switch in a circuit to apply electrical energy across the piezo and provide active control.

FIGURE 1A illustrates general aspects of a sports implement 50' in accordance with applicant's invention. Here a single sensor/actuator sheet element 56 covers a region R' of the ski and its strain-induced electrical output is shown connected by control unit 24 (not specifically shown) across a shunt loop 58. Shunt loop 58 contains a resistor 59 and filter 59' connected across opposed, e.g., top and bottom, electrodes of the actuator 56, so that as strain in the region R creates charge in the actuator element 56, the charge flows through the resistor 59 and is dissipated. The mechanical effect of

this construction is that strain changes occurring in region R' within the band of filter 59' are continuously dissipated, resulting, effectively, in damping of the plate-mechanical bending modes of the structure. While it is possible to entirely cover the ski with active material, in practice considerations of weight, strength and cost allow the element 56 to cover about five to ten percent of the surface, and to capture up to about five percent of the strain energy in the ski. The strain energy in the piezo alters the piezo charge state, and the filter/shunt then returns and dissipates this charge to reducer the strain energy in the ski. Since most vibrational states actually take some time period to build up, this continuous low level of mechanical compensation is effective to control serious mechanical effects of vibration, and to noticeably alter the response of the ski. In the present invention, by choosing the filter to target one or more resonant modes of the ski, the practically-occurring vibrations are addressed. In particular, by placing a resonant shunt across the piezo, the voltage induced across the shunt may be raised at the targeted frequency and the rate of power dissipation is enhanced. In the present invention, by selecting the values of the circuit elements in the shunt to provide a resonant voltage enhancement, particularly an inductive, low Q resonant enhancement, one preferentially increases the energy dissipation, hence damping, across a specific band, thus tailoring the damping response to be more robust in that specific band, or to be suitable for a specific ski construction or set of conditions. This implements a specific damper characteristic. Such a resonant shunt loop is shown in FIGURE 1B. Here, an inductor is added to the shunt to increase the voltage across the shunt, while an additional resistance is added, detuning the R-L-piezo resonance in a manner to optimize power dissipation as discussed further below.

As noted in the aforesaid Sports Implement international patent application, in practice, the intrinsic capacitance of the piezoelectric actuators operates to filter the signals generated thereby or applied thereacross, so that a separate filter element 59' need not necessarily be provided, and in a simple construction the piezo charge may be simply shunted through a suitable resistor.

One generally useful construction of this type described in the aforesaid international patent application and illustrated in figure 1B of that application was a resistively shunted construction in which three lead zirconium titanate (PZT) ceramic sheets PZ were laminated to flex circuit material in which corresponding trellis-shaped conductive leads C spanned both the upper and lower electroded surfaces of the PZT plates. Each sheet was 1.81 by 1.31 by 0.058 inches, forming a modular card-like assembly approximately 1.66 x 6.62 inches and 0.066 inches thick. The upper and lower electrode lines C extend to a shunt region S at the front of the modular package, in which they are interconnected via a pair of shunt resistors so that the charge generated

across the PZT elements due to strain in the ski is dissipated. The resistors are surface-mount chip resistors, and one or more surface-mount LED's 70 are connected across the leads to flash as the wafers experience strain and shunt the energy thereof. This provides visible confirmation that the circuit lines remain connected. The entire packaged assembly was mounted on the top structural surface layer of a ski to passively couple strain out of the ski body and continuously dissipate that strain. Another prototype damped ski employed four PZT ceramic sheets arranged in a line. Reference is made to the aforesaid Sports Implement patent application for a more complete description of the constructions contemplated for actuator placement, and regimens for shunting or actuating the piezo sheets. When used with a sensor and piezo drive circuit, for example, the active circuit elements 26 may include elements for amplifying the level of signal provided to the actuator and processing elements, for phase-shifting, filtering and switching, or logic discrimination elements to actively apply a regimen of control signals determined by a control law to the electroactive elements 25. In the latter case, all or a portion of the controller circuitry is preferably distributed in or on the planar actuator assembly, or on sensing elements of the electroactive assembly itself, for example as embedded or surface mounted amplifying, shunting, or processing elements as described in the aforesaid U.S. patent.

When this construction is employed to damp a sports implement, the damping factor of the damper depends on its dissipation of strain energy. Since the exact vibrational frequencies of a sports implement are not known or readily observable due *inter alia* to the variability of the human using it and the conditions under which it is used, one approach is to apply a broad band passive shunt. In the passive construction of FIGURE 1A, dissipation may be achieved with a simple resistive shunt circuit attached to the electroactive elements. However, in accordance with the present invention, a narrower but band-optimized shunt tuned to assure effectiveness at a particular condition is provide, or else a switchable set of shunts, such as resistors tuned in relation to the capacitance of the piezo sheet, to optimize the damping in the damper near the specific frequencies associated with the modes to be damped.

For targeting a specific frequency, the optimal shunt resistor is found from the vibration frequency and capacitance of the electroactive element as follows:

$$R_{opt} = al * (1/(\omega c)) \qquad (1)$$

where the constant *al* depends on the coupling coefficient of the damping element. One ski employed a piezoceramic damper module as described in the above-referenced U.S. patent, with the shunt circuit connected to the electroactive elements via flex-circuits which, together with epoxy and spacer material, form an integral damper assembly. Preferably an LED is placed across the actuator electrodes, or a pair of LEDs are placed

across legs of a resistance bridge to achieve a bipolar LED drive at a suitable voltage, so that the LED flashes to indicate that the actuator is strained and shunting, i.e., that the damper is intact and operating. This configuration is shown in FIGURE 1A by LED 70. As noted in the aforesaid patent application such an optimized resistive shunt damper design added only 4.2% in weight to the ski, yet was able to add 30% additional damping. The materials of which the ski was manufactured were relatively stiff, so the natural level of damping was below one percent. The additional damping due to a shunted piezoelectric sheet actuator amounted to about one-half to one percent damping, and this small quantitative increase was unexpectedly effective to decrease vibration and provide greater stability of the ski. The aforesaid design employed electroactive elements over approximately 10% of the ski surface, with the elements being slightly over 1/16th of an inch thick, and, as noted, it increased the level of damping by a factor of approximately 30%. The simple shunt resistance passively dissipates strain energy entering the electroactive element fairly uniformly over a broad range of frequencies.

The present invention in one aspect seeks to improve the damping in particular circumstances by providing a band-optimized shunt which more effectively damps a particular condition. In accordance with another aspect of the invention, two or more different circuit elements or shunt loops are selectively switched across a piezo sheet to allow the user to select a desired damping effect. Figure 2 illustrates one situation addressed by the present invention and shows a plot of amplitude versus frequency of the vibrational response of a ski to two different sets of ski conditions, denoted by a solid line A and a dashed line B. As generally illustrated in Figure 2, the ski has a number of vibrational modes at frequencies f_1, f_2, f_3... which illustratively in one tested ski were centered at approximately 12, 60, and 110 Hz. The solid line in the Figure illustrates the relative amplitudes of these vibrational states excited during slow skiing, while the dotted line illustrates the relative amplitudes of these modes occurring at a much faster speed. While each of the principal modes is excited at both speeds, the lower frequency modes are excited with greater amplitude at lower ski velocity, while and the higher frequency modes achieve greater amplitudes at high speed. This occurs because the higher speeds cause more frequent bumps and impulses which are better aligned to stimulate the higher frequency vibrational modes. As shown in Figure 2, the first mode is actually excited to a lesser extent during high speed skiing than during low speed skiing, and, in fact, its amplitude may be already less than the low speed first mode vibration after damping by a simple resistive shunt as shown in Figure 1A. On the other hand, the amplitudes of the second and higher modes grow with ski velocity, and under some conditions such as particular snow texture or topography further

discriminatory excitations may occur, which would, for example substantially increase the amplitude of the second mode, or the third mode vibration.

As shown in FIGURE 4, in one aspect the present invention addresses this variable response of the ski by providing shunts 58, 58' ...each of which has a power dissipation characteristic, or spectral effect, matched to a particular ski response or class of responses. Thus, for example, one shunt 58 may be tuned to effectively dissipate charge at frequency f_1 while a second may be tuned to damp the sharp high speed resonance at f_3. Yet a third shunt might be targeted at the entire band below f_3, to provide generally enhanced stability at all beginner/intermediate conditions. The remotely-switched circuit 24 (FIGURES 1 and 4) thus allows the user to switch in a passive shunt that selectively operates with higher efficiency at a particular resonance band such as the second, or the second and third modes, characteristic of higher speed skiing, or to operate at the first mode excited by low speed skiing.

Skipping ahead briefly, FIGURE 4 illustrates a basic embodiment 100 of this aspect of the invention, wherein a transmitter 35' is actuated by the skier to transmit a selection signal determined via selection switch 35a — for example to transmit an RF signal which may for example be tone modulated at one of a number of frequencies F_1, F_2... that each code for one selected damping shunt 58, 58'.... These signals are received and demodulated by receiver 38 which applies the received control signal to toggle or actuate a shunt switch 39 and thus place the selected one of the shunts across the strain element PZ. Each shunt is preferably provided with an LED indicator which lights up during operation when charge is applied across its shunt. Thus, when a selected shunt has been switched into the circuit across the piezo, charge flows through that shunt and its LED flashes as the ski moves. The various LEDs may be positioned under corresponding graphic windows printed in the top surface of the ski, and these in turn may be provided with legends or pictographs indicating the damping effect, such as high speed chatter damping, sun bowl vibration quieting, or other brief description of the targeted effect of the selected shunt. By way of example, the transmitter may simply employ fixed tones to modulate an RF signal, so that for example selection of shunt 58 is indicated by a 30 KHZ modulation, shunt 58' by a 35KHZ modulation etc. In that case, the RF signal may be demodulated and supplied in parallel toa set of band pass filters each of which passes one of the frequencies, and the output of each filter may then be simply connected as a gate or control voltage to a switch which places the corresponding shunt across the piezo assembly. In this case, all shunts are fixedly in place, and only one switch closes at a time. In other embodiments, the receiver/demondulator/switch may employ digital codes to convey selection information and to control switches or a switch array. The receiver may further include an answer

back transmitter or acknowledgment transponder that allows the sending unit to receive and display the selected mode or shunt. Preferably, however, the transmitter transmits a simple pulse, or coded pulse train, and the ski-mounted unit has a cyclic switch that simply connects the next shunt each time a pulse or pulse train is received. A charge storage capacitor may be provided to illuminate the selected LED even when the ski is stationary, so that the skier simply observes the display to ascertain which damping mode has been selected.

As noted above, higher modes are more greatly excited during faster, more energetic or more expert skiing. In order to more effectively damp these higher modes with the same piezo damper sheet assembly, one preferred embodiment of the present invention employs a tuned passive shunt to selectively operate with higher efficiency at a particular resonance band. This may be the second, or the second and third modes, characteristic of higher speed skiing, or may be configured to operate at the first mode excited by lower speed skiing.

In designing a piezoceramic plate shunt one faces several limitations. First, the plates themselves are necessarily manufactured in standard sizes and have a fixed capacitance range as a function of their area, dielectric properties and thickness. By placing a shunt resistor across the plates the shunted capacitance will have characteristic output voltage, hence feedback current, which places an upper limit on the efficiency of its operation. By tuning the shunt circuit to the same frequency as a mode of the ski, it may be possible to shunt more of the energy of that mode. However, a second constraint is that apparently identical skis may be manufactured in different sizes, with a corresponding shift in their resonance modes, or may be manufactured with variations and tolerances of components that result in a shift of the modes, so that, for example, the second resonance of a ski may fall at 55 or 65 Hz, rather than a nominal 60 Hz value. In that case, a shunt tuned to optimally damp a 60 Hz resonance will prove less effective for a shifted resonance.

Applicant has therefore determined to not simply tune a control circuit to effectively shunt a particular frequency, but to provide a robust shunt that operates effectively to shunt with enhanced efficiency over a band of expected frequencies. This band may include frequency variations due to manufacturing tolerances, temperature-induced variations, or circuit component variations.

The present invention in accordance with this aspect addresses these several constraints with a construction providing a shunt circuit having an inductive element which tunes the circuit to a nominal resonant frequency but has a Q optimized to include a performance band extending on either side of the resonance.

FIGURES 3 and 3A illustrate this situation. In FIGURE 3, there is shown a damping response of a ski having a nominal resonance at 100 Hz and damped by a highly tuned resonant shunt. As shown, the highly tuned shunt reduces amplitude of the 100 Hz center frequency from an initial value of 1.0 to approximately 15% of that value, with the greatest damping occurring at the center frequency. In operation the values of the shunt circuit elements across the piezo sheet are selected to resonate at the modal resonance, illustratively 100 Hz, so that when the piezo is strained at that frequency the voltage across the piezo plates is higher and a higher current flows through the resistor, maximizing the power, i^2R, dissipated by the shunt. However, when the shunt circuit is sharply tuned to a single resonance, it considerably less effective at damping vibrations near, but not at, the resonance. Applicant undertook to model the relative effectiveness of the shunt damper given an expected range of modal frequencies. FIGURE 3A illustrates the effect of such a highly tuned resonant shunt on three separate peaks at 90, 100 and 110 Hz, respectively. The solid lines indicate net amplitude of the three peaks, each assumed to have been of unit amplitude. As shown, the highly tuned shunt is considerably less effective at damping resonances occurring 10 Hz to either side of the tuned band achieving only about 40% reduction of the peak amplitude instead of 80%.

Applicant therefore undertook to enhance damping over the range of expected frequency values. To determine a suitable tuning, applicant modeled each resonance of the ski as falling somewhere in a band which may, for example, extend 10% on either side of the nominal resonance, and assumed that the actual resonant frequency will also vary since it depends upon a number of parameters such as the type of terrain, the frictional properties of the underlying snow, and the particular portion or amount of ski area currently in contact with the terrain. Applicant provided a shunt circuit which, rather than having a relatively high resistance to narrowly tune the shunt resonance, or a low resistance to increase current without substantial resonant effect, provides a resistance that tunes the RLC circuit to provide a reasonable amount of damping over a broader band without attaining the high peak damping at a center frequency. In FIGURE 3A, the dashed lines indicate the amount of damping modeled for this shunt for three separate peaks at 90, 100 and 110 Hz, each originally of unit amplitude. As shown, an effective level of damping in the range of 70% is obtained at the center frequency, while at the fringes a slightly lower level of 60% damping occurs at the center frequency. While the lower Q shunt allows the nominal 100Hz vibration to reach a level somewhat above the peak obtained from a highly tuned shunt, good damping is obtained for the other likely values of the third mode resonance. The damper is robust, in that it works effectively on substantially all skis of the production model, on substantially all terrains under the chosen (high speed) third mode excitation conditions.

When implemented in a production ski, the ski was found to have an expected third longitudinal resonance mode at approximately 112 Hz. A piezo plate damping assembly was constructed having three plates each 58 mils thick and 1.81 by 1.31 inches wide, arranged next to each other in one row in a single layer. Total plate capacitance was approximately

88 nf and an inductor of 22 Henrys was applied across the circuit in series with a resistance, that together with the inductor's resistance of 2.4 kΩ forms a 3.2 kΩ shunt across the plates, obtaining substantial resonant voltage increase over the frequency range 112 Hz ± 10%. The relatively high resistance value provides a lower Q resonance circuit, even through this entails lowering the current dissipated in the resistor from that of a higher Q "tuned" 112 Hz circuit.

The desired shunt characteristics were determined by modeling the system and adjusting parameters to minimize the H_2 response (in the control systems sense) of three systems simultaneously. One system was taken to have a resonance frequency equal to the nominal frequency of the target mode, 112 Hz. The second had a resonance equal to the minimum expected resonant frequency for that mode, and the third had a resonance equal to the maximum expected frequency of that mode. The optimization was done in the minmax sense:

$$R_{opt}, L_{opt} = \min_{R,L} \max \left(G_1(R,L), G_2(R,L), G_3(R,L)\right)$$

Where G_1 is the H_2 (or H_∞) response of the nominal system as a function of R and L, and G_2 and G_3 are the corresponding responses for the systems with frequency set to the maximum and minimum expected values of the resonant frequency, f_1, f_2, f_3 above. The minimax calculation was performed in a straightforward way using the MFILES language of MATLAB, and the values of R, L were chosen to optimize power dissipation through the shunt for the composite system constraints, e.g. the RMS energy over the band (H_2) or the total energy at the three frequencies (H_∞). A relatively large resistance value was chosen to tune the shunt to provide substantial damping over a range of expected modal or excitation frequencies. Further, the inductor was allowed to saturate since this saved substantial weight in the assembly.

The foregoing shunt design results in a robust shunt that produces dependable level of damping without unexpected performance loss when changes in operating conditions or terrain occur, and without extreme loss of efficiency when faced with manufacturing variations and device tolerances. In particular, by designing a broad band inductive shunt, component tolerances could be allowed a wide degree of latitude, with low tolerance resistors having values varying by up to 5%, the inductor values varying up to 15% and the plate capacitance of the piezo sheets up to 10% in either direction.

The entire circuit is capable of substantial miniaturization. The inductor was wound on a core which was mounted mid-plane in the circuit board forming the piezo strain control unit, and thus extended partly into the ski below the surface of the ski. The resistance elements were chip mounted resistors centered between conductive lines of the strain element circuit package, and also sealed beneath the surface of the ski. The technique is of general applicability and corresponding resistance and inductance values are readily calculated for the different capacitance of strain control modules having any number of piezo sheets, or pairs of piezo sheets in the damping assembly, as well as for optimizing control of different vibrational modes.

Greater areas of actuation material could be applied with either the passive or an active control regimen to obtain more pronounced damping affects. Furthermore, as knowledge of the active modes a ski becomes available, the invention contemplates particular switching or control implementation may be built into the damper or into separate drive or shunt circuitry to specifically attack such problems as resonant modes which arise under particular conditions, such as hard surface or high speed skiing, or to select the damped modes by switching between different feedback shunts as conditions vary.

The piezo assembly is also capable of selectively increasing vibration. This may be desirable to excite ski modes which correspond to resonant undulations that may in certain circumstances reduce frictional drag of the running surfaces. It may also be useful to quickly channel energy into a known mode and prevent uncontrolled coupling into less desirable modes, or those modes which couple into the ski shapes required for turning. One embodiment of a ski may simply have a switch to render the assembly operative. When switched ON, it either passively shunts and damps the ski, or is actively driven to stiffen the ski or to dynamically control ski response. When switched OFF, it functions simply as stiff, but inert, structural material and the ski behaves with its normal stiffness, vibrational response etc.

In addition to the applications to a ski described in detail above, the present invention has broad applications as a general sports damper which may be implemented by applying the simple modeling and design considerations as described above. Thus, corresponding actuators may be applied to the runner or chassis of a luge, or to the body of a snowboard or cross country ski. Furthermore, electroactive assemblies may be incorporated as portions of the structural body as well as active or passive dampers, or to change the stiffness, in the handle or head of sports implements such as racquets, mallets, golf clubs and sticks for which the vibrational response may affect the players' handling rather than or in addition to the object being struck by the implement. It may also be applied to the frame of a sled, bicycle or the like. In each case, the sports

implement of the invention is constructed by modeling the modes of the sports implement, or detecting or determining the location of maximal strain for the modes of interest, and applying electroactive assemblies material at the regions of high strain, and shunting or energizing the material optimally dissipate energy over a performance or tolerance band around one or more nominal modes to control the device.

FIGURES 5A and 5B illustrate representative golf club 90 and tennis racquet 100 embodiments of the invention, respectively. As shown in FIGURE 5A, a club 90 having a head 91, a shaft 92 and a handle 93 contains an assembly of strain actuation material 92a, shown in a sectional view attached near the handle 93 to control vibration such as the bending modes and/or shock traveling along the shaft. The racquet 100 shown in FIGURE 5B similarly has electroactive or smart material 110 mounted within the handle, where it is located to receive high strain without, however undergoing destructively high deformations or imbalancing the racquet. The construction may be further applied to implements such as baseball bats, sports vehicles and the like, as described more fully in the aforesaid international application, and with the improvements described herein.

Returning to a discussion of the material placement, rather than modeling vibrational modes of a sports implement to determine an optimum placement for a passive sensor/actuator or an active actuator/sensor pair, the relevant implement modes may be empirically determined by placing a plurality of sensors on the implement and monitoring their responses as the implement is subjected to use. Once a "map" of strain distribution over the implement and its temporal change has been compiled, the regions of high strain are identified and an actuator is located, or actuator/sensor pair interlocated there to affect the desired dynamic response. Thus, the invention further contemplates that the controller may operate to switch between different sets of actuators which are place, for example, in two different strain regions that are excited under different conditions. The switching may be accomplished by a user-controlled remote unit, or be a sensor-responsive and automatic operation. For example, temperature sensor may trigger a switch to higher-mode suppression to enhance performance in faster snow conditions characteristic of extreme cold.

The two aspects of the invention-- enhanced shunt dissipation and the operation of multiple shunts may be applied to other sports implements. A ski interacts with its environment by experiencing a distributed sliding contact with the ground, an interaction which applies a generally broad band excitation to the ski. This interaction and the ensuing excitation of the ski may be monitored and recorded in a straightforward way, and may be expected to produce a relatively stable or slowly evolving strain distribution, in which a region of generally high strain may be readily identified for optional

placement of the electroactive assemblies. A similar approach may be applied to items such as bicycle frames, which are subject to similar stimuli and have similarly distributed mechanics.

An item such as mallet or racquet, on the other hand, having a long beam-like handle and a solid or web striking face at the end of the handle, or a bat with a striking face in the handle, generally interacts with its environment by discrete isolated impacts between a ball and its striking face. As is well known to players, the effect of an impact on the implement will vary greatly depending on the location of the point of impact. A ball striking the "sweet spot" of a racquet or bat will efficiently receive the full energy of the impact, while a glancing or off-center hit with a bat or racquet can excite a vibrational mode that further reduces the energy of the hit and also makes it painful to hold the handle. For these implements, the discrete nature of the exciting input makes it possible to excite many longitudinal modes with relatively high energy. Furthermore, because the implement is to be held at one end, the events which require damping for reasons of comfort, will in general have high strain fields at or near the handle, and require placement of the electroactive assembly in or near that area. However, it is also anticipated that a racquet may also benefit from actuators placed to damp circumferential modes of the rim, which may be excited when the racquet nicks a ball or is impacted in an unintended spot. Further, because any sports implement, including a racquet, may have many excitable modes, controlling the dynamics may be advantageous even when impacted in the desired location. Other sports implements to which actuators are applied may include luges or toboggans, free-moving implements such as javelins, poles for vaulting and others that will occur to those skilled in the art.

The actuators may also be powered to alter the stiffness of the shaft of a golf club or to affect its head. In general, when applied to affect damping, increased damping will reduce the velocity component of the head resulting from flexing of the handle, while reduced damping will increase the attainable head velocity at impact. Similarly, by energizing the actuators to change the stiffness, the "timing" of shaft flexing is altered, affecting the maximum impact velocity or transfer of momentum to a struck ball.

As indicated above for the passive constructions, control is achieved by coupling strain from the sports implement in use, into the electroactive elements and dissipating the strain energy by a passive shunt or energy dissipation element. In an active control regimen, the energy may be either dissipated or may be effectively shifted, from an excited mode, or opposed by actively varying the strain of the region at which the actuator is attached. Thus, in other embodiments they may be actively powered to stiffen or otherwise alter the flexibility a shaft or body.

The invention being thus disclosed and described, further variations will occur to those skilled in the art, and all such variations and modifications are consider to be with the spirit and scope of the invention described herein and its equivalents, as defined in the claims appended hereto.

What is claimed is:

Claims

1. A ski comprising

a ski body

an electroactive assembly mounted on said ski body and including electroactive material for transducing electrical energy and mechanical strain energy, said electroactive assembly being coupled to said body in a region of strain, and

a control circuit placed across said electroactive assembly and operative to preferentially alter dynamic response of said ski body to a defined ski condition.

2. A ski according to claim 1, wherein the defined ski condition excites a mode of the ski and said control circuit includes an inductive shunt across the eletroactive material and tuned to enhance damping in a frequency band about the mode.

3. A ski according to claim 1, wherein the control circuit includes a switch and is operable to select among circuit elements to preferentially damp a specific vibrational mode of the ski body.

4. A ski according to claim 2, wherein the inductive shunt is a band optimized shunt centered at about 110Hz.

5. A ski according to claim 1, wherein said defined ski condition excites structural modes of said ski body giving rise to a strain distribution including a region of high strain, and said assembly is coupled in the region of high strain to shift or damp excitation of modes and thereby improve handling of said ski.

6. A ski according to claim 3, wherein said control circuit includes plural shunts each optimized for dissipating energy differently in bands corresponding to different respective ski conditions.

7. A ski according to claim 2, wherein said inductive shunt includes an inductor of a size to saturate with electrical energy generated by said electroactive material.

8. A ski according to claim 2, wherein said inductive shunt includes an inductor and a resistor which, together with intrinsic capacitance of said assembly, forms a resonance over said narrow frequency band.

9. A ski according to claim 8, wherein the resistor detunes resonance about a frequency in said band, decreasing sensitivity to manufacturing tolerances so that the shunt operates robustly to dissipate electrical energy for a range of manufacturing and size variation of the ski.

10. A ski according to claim 3, wherein said switch is a manually or electrically controlled switch.

11. A ski according to claim 3, wherein said switch is an electrically controlled switch which is remotely controlled by the user or is automatically actuated by the control circuit in response to a sensed condition.

12. A ski according to claim 9, wherein said band encompasses a ski free resonance frequency and a tolerance band corresponding to variations about frequency of the resonance in use.

13. A ski according to claim 10, wherein said switch operates an inductive shunt tuned to preferentially damp oscillation in a frequency band centered around a nominal ski body mechanical mode which is stimulated under a first defined set of operating conditions.

14. A ski according to claim 11, wherein said switch is a remotely-controlled switch and further comprising a control transmitter for transmitting a signal to change switch states.

15. A ski according to claim 14, wherein said control transmitter includes means for being worn or carried by a user.

16. A ski according to claim 11, including a plurality of shunt circuits selectively connected by said switch and effective to damp ski vibration under a plurality of different sets of operating conditions.

17. A ski according to claim 16, wherein said sets of operating conditions include at least one of

i) a low speed operating condition and a high speed operating condition
ii) a beginner skier operating condition and an expert skier operating condition, and
iii) operating conditions characteristic of different types of snow or terrain.

18. A method of controlling a ski, such method comprising the steps of

locating an area of high strain which occurs in a ski under a range of skiing conditions

mounting electroactive strain material on the ski in said region of high strain, and

placing a shunt across the electroactive strain material, wherein the shunt is a band-limited shunt with an effective frequency band targeted to a specific mode stimulated by an operating condition of the ski so as to enhance damping under a subset of said range of skiing conditions which preferentially stimulate the specific mode.

19. The method of claim 18, wherein the shunt is an inductive shunt tuned in relation to capacitance of said material so as to encompass a band about a second or higher longitudinal bending mode of the ski.

20. The method of claim 18, wherein said shunt is effective to reduce peak vibration amplitude between about twenty and eighty percent over a range of frequencies encompassing said specific mode, said range including frequency variations of the mode due to operating conditions or manufacturing tolerances.

21. The method of claim 20, wherein said shunt is tuned to enhance dissipation of electrical energy at frequencies inside of said range of frequencies and away from an adjacent mode of the ski.

22. The method of claim 18, wherein the step of placing a shunt includes the step of providing a switch to place the shunt in circuit with the strain element, said switch being configured for switching between two shunt values for selectively enhancing damping under at least two different operating conditions of the ski.

23. The method of claim 22, wherein said switch switches in different shunts configured to enhance damping at different speeds of ski operation.

24. The method of claim 22, wherein said switch is a remotely-actuable switch whereby the user may select operation of a circuit by remotely acuating the swithch.

25. A method of damping a sports implement, such method comprising

locating a region of high strain in the sports implement

mounting electroactive material on the sports implement in said region to receive strain energy therefrom and produce electrical charge which varies with said strain energy, and

shunting said charge to alter strain in said region thereby changing response of the body in use, by placing an inductive shunt across the electroactive material, wherein the inductive shunt is tuned to resonate over a band containing a nominal resonant mode of the implement whereby said resonant mode is effectively damped.

26. The method of claim 25, wherein the sports implement includes a switch for controlling shunting across the electroactive material.

27. The method of claim 25, wherein the sports implement is selected from among a bat, a golf club, a racquet, a snowboard, a ski and a runnered vehicle, and the step of shunting includes preferentially shunting a frequency band to selectively damp a targeted mode of a corresponding bat, golf club head or shaft, racquet head or shaft, snowboard, ski or a runner of the vehicle, respectively.

28. The method of claim 25, wherein the step of shunting includes shunting in a circuit having a Q tuned to optimize damping over a band width encompassing dynamic or component-induced variation of a resonance frequency.

29. A sports implement comprising

a body

an electroactive assembly mounted on said body and including electroactive material for transducing electrical energy and mechanical strain energy, said electroactive assembly being coupled to said body in a region of strain, and

an inductor circuit tuned to alter dynamic response of said body to stimulation that arises under use.

30. A sports implement according to claim 29, which is a ski, and further comprising a switch connected to said assembly for selectively placing said inductor circuit across said assembly to adapt the ski to conditions of use.

31. A ski according to claim 30, comprising a plurality of circuit elements, and wherein said switch is configured to selectively connect ones of said circuit elements to said electroactive material to achieve a plurality of different damping effects on said ski body in use.

32. A method of damping a ski, such method comprising the steps of

mounting an electroactive strain element on the ski to transduce strain energy to electrical energy

providing a plurality of circuit elements on the ski, and

providing a switch configured to selectively connect said circuit elements across the strain element to dissipate the electrical energy and achieve damping.

33. The method of claim 32, wherein the step of mounting an electroactive strain element on the ski includes incorporating a layer including piezoceramic material in the ski, and one of said circuit elements is an inductive element tuned in relation to capacitance of said layer to damp a performance mode of the ski.

34. The method of claim 33, wherein said inductive element forms a shunt effective to reduce peak vibration amplitude between about twenty and eighty percent over a range of frequencies encompassing said performance mode, said range including frequency variations of the mode due to operating conditions or manufacturing tolerances.

35. The method of claim 32, wherein said circuit elements include at least one circuit for dissipation of electrical energy at a range of frequencies, and another circuit for enhanced dissipation of energy at a higher vibrational mode of the ski.

36. The method of claim 32, wherein the step of providing a switch includes providing a remotely-actuable switch.

37. The method of claim 36, wherein said remotely-actuable switch is an RF-actuated switch, and further comprising the step of providing an RF transmitter for selectively switching said RF-actuable switch.

38. A performance ski system comprising

a ski

a damper formed of smart material mounted on the ski for coupling strain energy from the ski

a plurality of shunt elements, and

a switch for controllably and selectively placing one of said shunt elements across the smart material to dissipate its strain energy and thereby damp the ski.

39. A performance ski system according to claim 38, wherein the switch is a remotely-controlled switch mounted on the ski, and the system further comprises a transmitter for remotely selecting a switch state of said switch.

40. A performance ski system according to claim 39, wherein the switch is electrically actuated, and further comprising electrical charge storage means, mounted on the ski, for actuating the switch.

41. A performance ski comprising

a ski body, said ski body having a mode which is stimulated in use at a characteristic frequency, the characteristic frequency being subject to variation within a band about a nominal frequency

an assembly including electroactive strain material mounted on said ski for transducing electrical energy and mechanical strain energy, and

a circuit placed across the electroactive strain material to dissipate electrical energy, said shunt circuit being configured so that together with said material the circuit resonates over said band about the nominal frequency to effectively damp said ski body in use.

42. A performance ski comprising

a ski body, said ski body having a plurality of modes which are stimulated in use at characteristic frequencies,

an assembly including electroactive strain material mounted on said ski for transducing electrical energy and mechanical strain energy, and

a switchable circuit placed across the electroactive strain material to alter electrical energy therein and thereby affect mechanical performance of the ski, wherein said switchable shunt circuit is configured for remote actuation to selectively change between different desired performance characteristics of the ski.

43. A method of damping a ski, such method comprising the steps of

mounting an electroactive strain element on the ski to transduce strain energy to electrical energy

providing at least one shunt circuit on the ski, and

providing a switch configured to selectively connect one of said shunts across the strain element to dissipate the electrical energy and achieve damping when the switch is actuated.

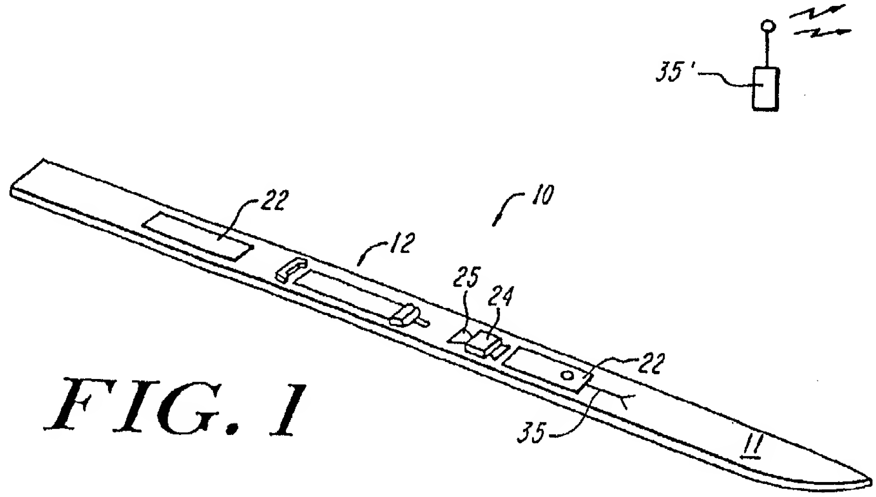


FIG. 1

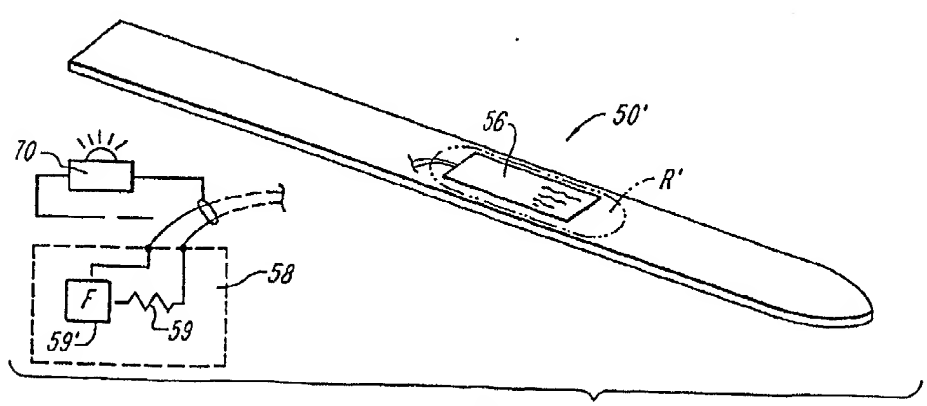


FIG. 1A

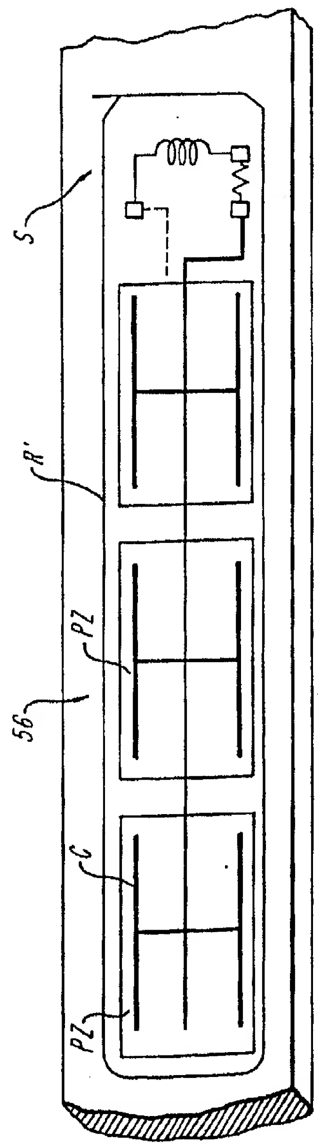


FIG. 1B

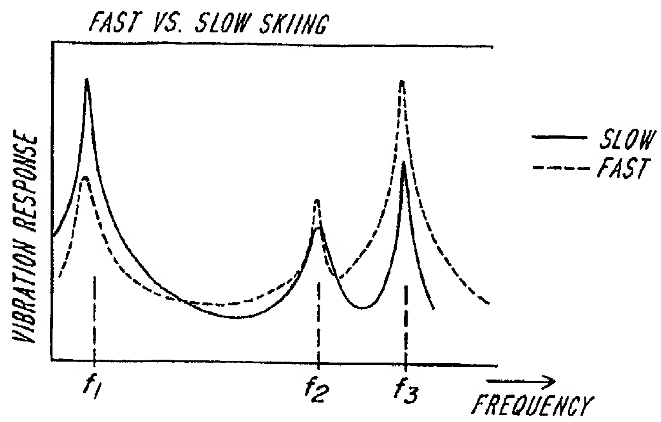

FAST VS. SLOW SKIING
VIBRATION RESPONSE
SLOW
FAST
f1
f2
f3
FREQUENCY

FIG. 2

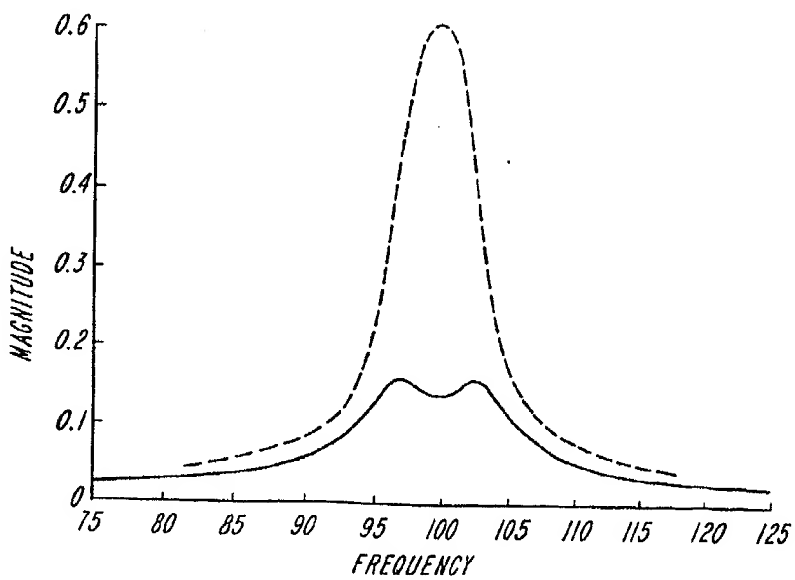

0.6
0.5
0.4
0.3
0.2
0.1
0
MAGNITUDE
75
80
85
90
95
100
105
110
115
120
125
FREQUENCY

FIG. 3

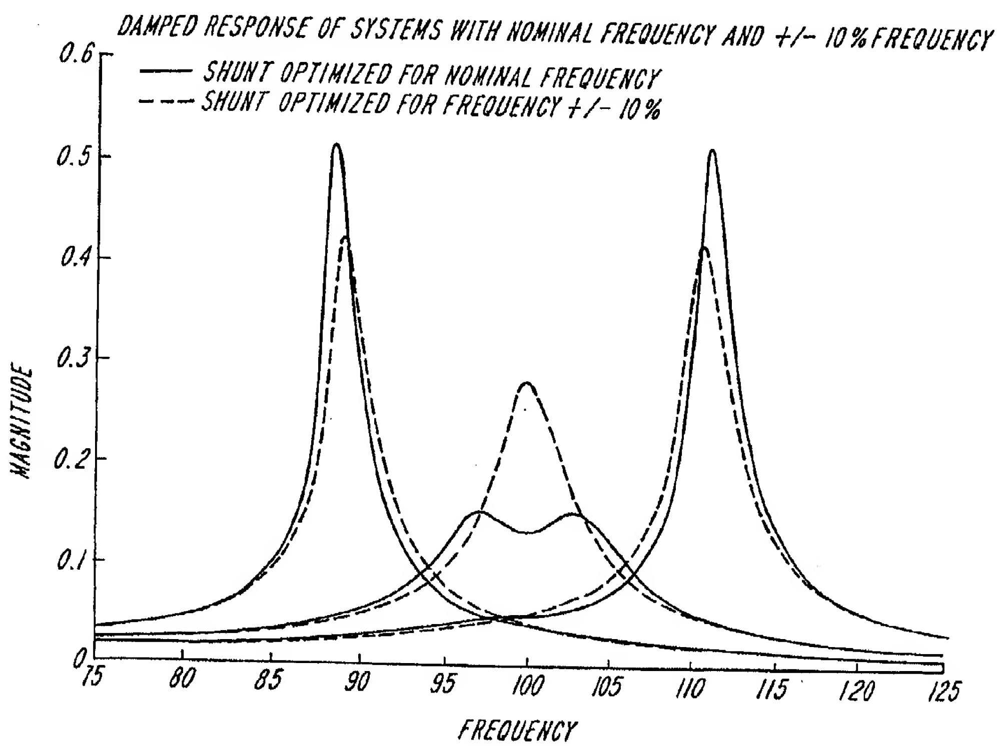
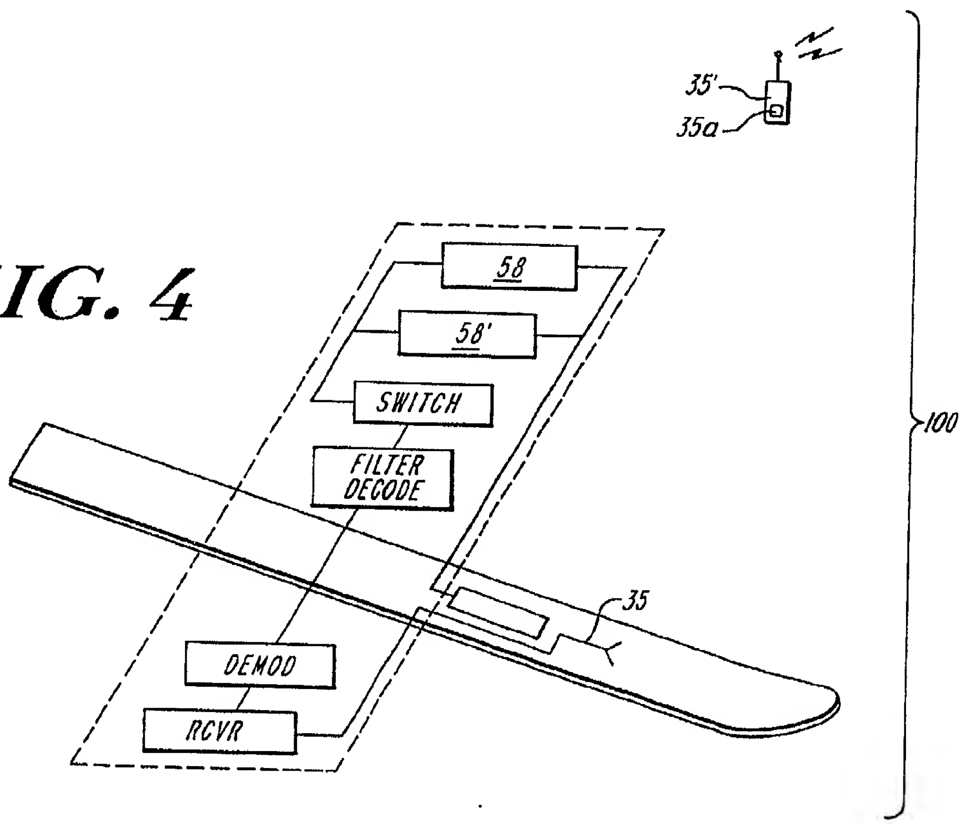

DAMPED RESPONSE OF SYSTEMS WITH NOMINAL FREQUENCY AND +/- 10% FREQUENCY
SHUNT OPTIMIZED FOR NOMINAL FREQUENCY
SHUNT OPTIMIZED FOR FREQUENCY +/- 10%
MAGNITUDE
0.6
0.5
0.4
0.3
0.2
0.1
0
75
80
85
90
95
100
105
110
115
120
125
FREQUENCY

FIG. 3A

FIG. 4



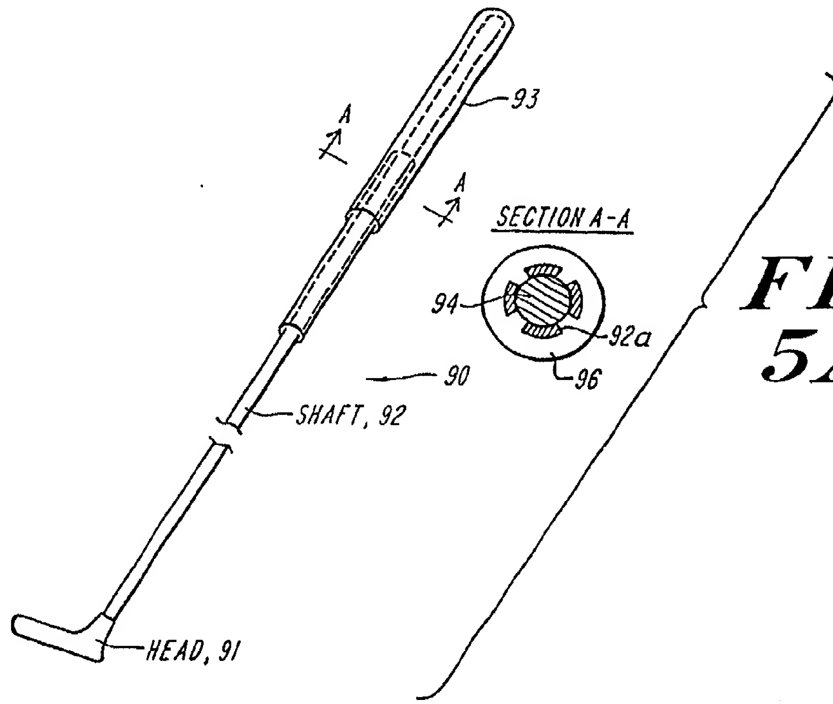

93
A
A
SECTION A-A
94
92a
96
90
SHAFT, 92
HEAD, 91

FIG. 5A

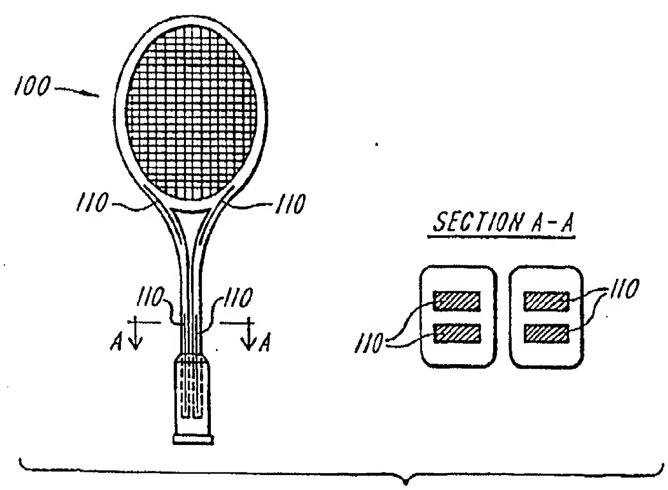

100
110
110
SECTION A-A
110
110
A
A
110
110

FIG. 5B

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 98/02132

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 A63C5/075

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 A63C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ASHLEY S: "SMART SKIS AND OTHER ADAPTIVE STRUCTURES" MECHANICAL ENGINEERING, vol. 117, no. 11, 1 November 1995, pages 76-81, XP000539264 ---	1,18,25, 29,32, 38,41-43
P,X	WO 97 11756 A (ACTIVE CONTROL EXPERTS) 3 April 1997 see the whole document -----	1,18,25, 29,32, 38,41-43

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
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Date of the actual completion of the international search	Date of mailing of the international search report
2 June 1998	16/06/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Lasson, C

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INTERNATIONAL SEARCH REPORT

Information on patent family members

In' ational Application No
PCT/US 98/02132

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
WO 9711756	A	03-04-1997	NONE	

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